

Water Recovery System Design to Accommodate Dormant Periods for Manned Missions

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Future manned missions beyond lower Earth orbit may include intermittent periods of extended dormancy. Under the NASA Advanced Exploration System (AES) project, NASA personnel evaluated the viability of the ISS Water Recovery System (WRS) to support such a mission. The mission requirement includes the capability for life support systems to support crew activity, followed by a dormant period of up to one year, and subsequently for the life support systems to come back online for additional crewed missions. Dormancy could be a critical issue due to concerns with microbial growth or chemical degradation that might prevent water systems from operating properly when the crewed mission began. As such, it is critical that the water systems be designed to accommodate this dormant period. This paper details the results of this evaluation, which include identification of dormancy issues, results of testing performed to assess microbial stability of pretreated urine during dormancy periods, and concepts for updating to the WRS architecture and operational concepts that will enable the ISS WRS to support the dormancy requirement.

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Nomenclature

| | | | |
|-------|--|-------|----------------------------------|
| ACY | Russian Urinal | PWD | Potable Water Dispenser |
| AES | Advanced Exploration System | SPA | Separator Pump Assembly |
| ARFTA | Advanced Recycle Filter Tank Assembly | SPE | Solid Polymer Electrolysis |
| CCAA | Common Cabin Air Assembly | SRV-K | Russian Condensate Processor |
| CDRA | Carbon Dioxide Removal Assembly | TOCA | Total Organic Carbon Analyzer |
| CHX | Condensing Heat Exchanger | UPA | Urine Processor Assembly |
| CRS | CO ₂ Reduction System | USOS | United States On-orbit Segment |
| CWC | Contingency Water Container | VCD | Vapor Compression Distillation |
| DA | Distillation Assembly | WHC | Waste and Hygiene Compartment |
| ECLS | Environmental Control and Life Support | WPA | Water Processor Assembly |
| EDV | Russian Urine Container | WRM | Water Recovery Management |
| FCPA | Fluids Control Pump Assembly | WRS | Water Recovery System |
| ISS | International Space Station | WSTA | Wastewater Storage Tank Assembly |
| MCV | Microbial Check Valve | | |
| MF | Multi-Filtration | | |
| MLS | Mostly Liquid Separator | | |
| OGA | Oxygen Generator Assembly | | |
| OGS | Oxygen Generation System | | |
| ORU | Orbital Replacement Unit | | |
| PCPA | Pressure Control and Pump Assembly | | |
| psig | Pounds Per Square Inch, Gauge | | |

I. Introduction

The AES Water project has evaluated critical issues for a future manned mission beyond International Space Station (ISS), under the guideline of using ISS systems as the baseline for the system architecture. The mission requirements include operating the ECLS systems for periods of 30, 60, 90, and 180 days, with a dormant period between crewed missions that can last up to one year. Dormancy has been identified as a critical issue for future missions, due to concerns of microbial growth or chemical degradation that would prevent water systems from operating properly when the crewed mission began. The mission requirement includes the capability for life support systems to support crew activity, followed by a dormant period of up to one year, and subsequently for the life support systems to come back online for additional crewed missions. As such, it is critical that the water system be designed to accommodate this dormant period. To support this capability, this task has identified dormancy issues, completed relevant tests, and developed architecture and operational concepts that will support the dormancy requirement for future missions.

The initial phase of the FY13 task included an end-to-end assessment of the water management and recovery system, from the point at which water is initially collected in the urinal and condensing heat exchanger, to the use points for crew consumption or oxygen generation. Figure 1 provides a simplified schematic of the water system.

The following assumptions were defined for the initial assessment:

1. The reference mission will be comprised of 4 crew
2. The baseline water recovery system design is the current system in use on the International Space Station.
3. There are two sources of waste water, including pretreated urine and humidity condensate collected by the Condensing Heat Exchanger.
4. The current urine pretreatment (chromium trioxide and sulfuric acid) and an alternate formula (chromium trioxide and phosphoric acid) were evaluated
5. Power will be available during the dormant period to operate systems
6. The habitable volume for the vehicle is roughly equivalent to the International Space Station (ISS) Laboratory Module and Node 1
7. This assessment will be limited to the water system. The air revitalization system will be discussed only to the extent that the water system interacts with it.
8. Silver will be used as the biocide in the potable water
9. Atmospheric pressure inside the vehicle during use is 10.2 psi. Pressure during dormancy is unknown.

II. Description of the ISS Water Recovery and Management System

The ISS Water Recovery and Management (WRS) System provides the capability to receive the waste water on ISS (crew urine, humidity condensate, and Sabatier product water), process the waste water to potable standards via the WRS, and distribute potable water to users on the potable bus. The waste water bus receives humidity condensate from the Common Cabin Air Assemblies (CCAAs) on ISS, which condenses water vapor and other condensable contaminants and delivers the condensate to the bus via a water separator. In addition, waste water is also received from the Carbon Dioxide Reduction System. This hardware uses Sabatier technology to produce water from carbon dioxide (from the Carbon Dioxide Removal Assembly (CDRA)) and hydrogen (from the electrolysis process in the Oxygen Generation System). Waste water is typically delivered to the WPA Waste Tank, though the Condensate Tank located in the US Laboratory Module is available in the event the WPA Waste Tank is disconnected from the waste bus.

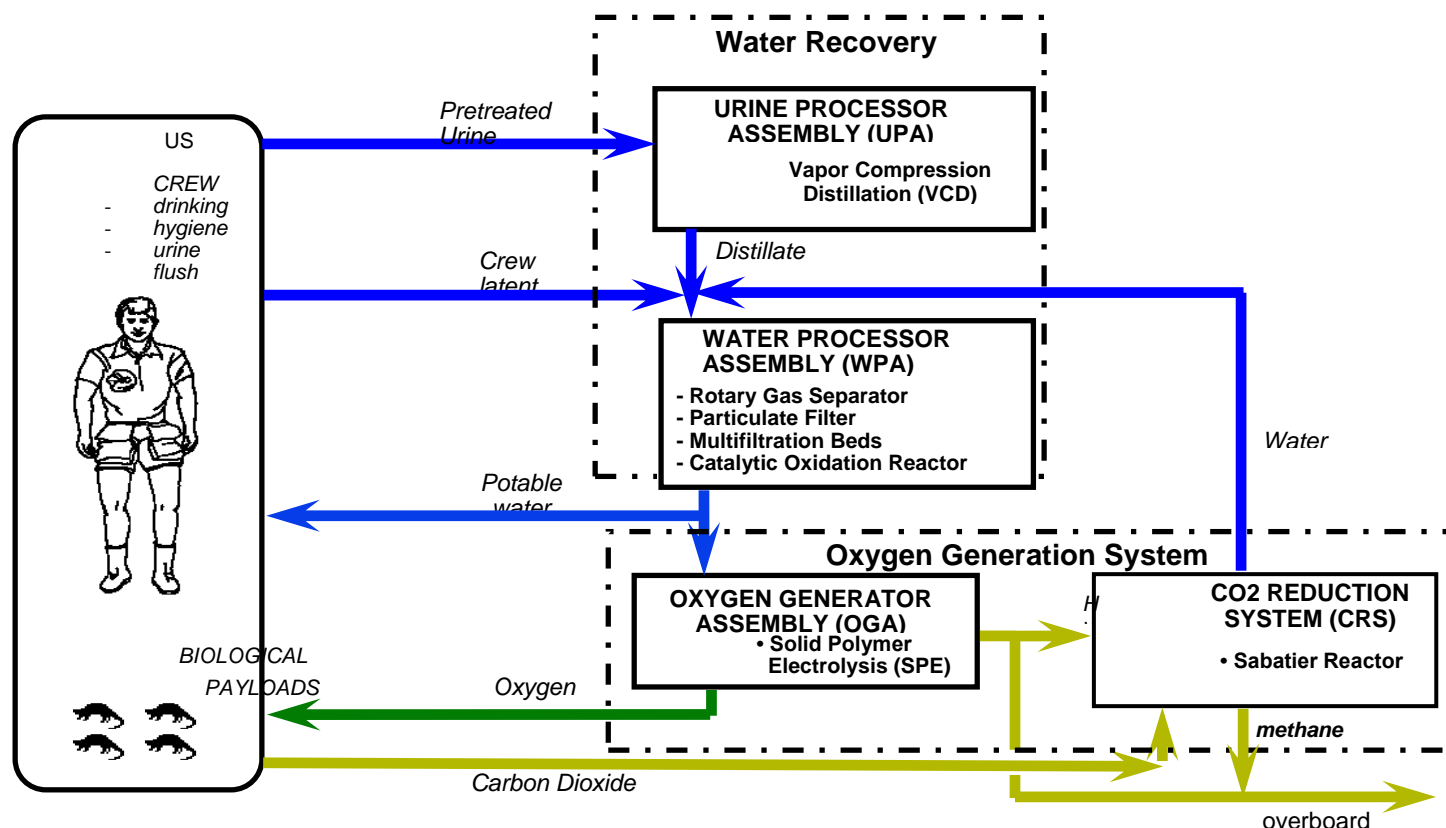


Figure 1. Water Recovery and Management Architecture for the ISS US Segment

Crew urine is collected in the Waste & Hygiene Compartment (WHC), which includes a Russian Urinal (referred to as the ACY) integrated for operation in the US Segment. To maintain chemical and microbial control of the urine and hardware, the urine is treated with chemicals and flush water. The pretreated urine is then delivered to the Urine Processor Assembly (UPA) for subsequent processing. The UPA produces urine distillate which is pumped directly to the WPA Waste Water Tank, where it is combined with the humidity condensate from the cabin and Sabatier product water, and subsequently processed by the WPA.

After the waste water is processed by the WRS, it is delivered to the potable bus. The potable bus is maintained at a pressure of approximately 230 to 280 kPa (19 to 26.5 psig) so that water is available on demand from the various users. Users of potable water on the bus include the Oxygen Generation System (OGS), the WHC (for flush water), the Potable Water Dispenser (PWD) for crew consumption, and Payloads.

Wastewater delivered to the WPA includes condensate from the Temperature and Humidity Control System and distillate from the UPA. This wastewater is temporarily stored in the Waste Water Tank Orbital Replacement Unit (ORU). The Waste Water Tank includes a bellows that maintains a pressure of approximately 5.2 – 15.5 kPa (0.75 to 2.25 psig) over the tank cycle, which serves to push water and gas into the Mostly Liquid Separator (MLS). Gas is removed from the wastewater by the MLS (part of the Pump/Separator ORU), and passes through the Separator Filter ORU where odor-causing contaminants are removed from entrained air before returning the air to the cabin. Next, the water is pumped through the Particulate Filter ORU followed by two Multifiltration (MF) Beds where inorganic and non-volatile organic contaminants are removed. Once breakthrough of the first bed is detected, the second bed is relocated into the first bed position, and a new second bed is installed. Following the MF Beds, the process water enters the Catalytic Reactor ORU, where low molecular weight organics not removed by the adsorption process are oxidized in the presence of oxygen, elevated temperature, and a catalyst. The Gas Separator ORU removes excess oxygen and gaseous oxidation by-products from the process water and returns it to the cabin. The Reactor Health

Sensor ORU monitors the conductivity of the reactor effluent as an indication of whether the organic load coming into the reactor is within the reactor's oxidative capacity. Finally, the Ion Exchange Bed ORU removes dissolved products of oxidation and adds iodine for residual microbial control. The water is subsequently stored in the Water Storage Tank prior to delivery to the ISS potable water bus. The Water Delivery ORU contains a pump and small accumulator tank to deliver potable water on demand to users.

The UPA was designed to process a nominal load of 9 kg/day (19.8 lbs/day) of wastewater consisting of urine and flush water. This is the equivalent of a 6-crew load on ISS. Pretreated urine is delivered to the UPA either from the USOS Waste and Hygiene Compartment (outfitted with a Russian urinal) or via manual transfer from the Russian urine container (called an EDV). In either case, the composition of the pretreated urine is the same, including urine, flush water, and a pretreatment formula containing chromium trioxide and sulfuric acid to control microbial growth and the reaction of urea to ammonia. The urine is temporarily stored in the Wastewater Storage Tank Assembly (WSTA). When a sufficient quantity of feed has been collected in the WSTA, a process cycle is automatically initiated. The Fluids Control and Pump Assembly (FCPA) is a four-tube peristaltic pump that moves urine from the WSTA into the Distillation Assembly (DA), recycles the concentrated waste from the DA into the Advanced Recycle Filter Tank Assembly (ARFTA) and back to the DA, and pumps product distillate from the DA to the wastewater interface with the WPA. The DA is the heart of the UPA, and consists of a rotating centrifuge where the waste urine stream is evaporated at low pressure. The vapor is compressed and subsequently condensed on the opposite side of the evaporator surface to conserve latent energy. A rotary lobe compressor provides the driving force for the evaporation and compression of water vapor. Waste brine resulting from the distillation process is stored in the ARFTA, which has a capacity of approximately 22 L. When the brine is concentrated to the required limit, the ARFTA is drained to a waste container and subsequently refilled with pretreated urine to initiate a new process cycle. The Pressure Control and Pump Assembly (PCPA) is another four-tube peristaltic pump which provides for the removal of non-condensable gases and water vapor from the DA. Liquid cooling of the pump housing promotes condensation, thus reducing the required volumetric capacity of the peristaltic pump. Gases and condensed water are pumped to the Separator Plumbing Assembly (SPA), which recovers and returns water from the purge gases to the product water stream.

III. Discussion

For the purpose of this assessment, the water system can be divided into the following primary regions. Each region possesses unique issues that are addressed in the following discussion.

- A. Untreated Urine
- B. Pretreated Urine and Brine
- C. Urine Distillate and Humidity Condensate
- D. WPA Waste Water
- E. WPA Process Water
- F. WPA Reject Line
- G. Potable Water
- H. Potable Distribution Bus

Untreated Urine

Untreated Urine will produce microbial growth relatively quickly in plumbing line or tanks. Though urine is sterile in the body, the organic content provides nutrients for bacterial and fungal growth once the urine is exposed to the ISS environment. To maintain microbial and chemical control, pretreatment chemicals are added to the urine as it is collected. These chemicals on ISS include chromium trioxide and sulfuric acid, though an alternate pretreatment is in development in which the sulfuric acid is replaced with phosphoric acid. The chromium trioxide functions as an oxidant, which is essential for preventing fungal growth. Since the pretreatment chemicals cannot be added at the same location as the urine, there is a short plumbing line that transfers the untreated urine to the section where the pretreatment chemicals are added. This line is replaced monthly on ISS, and the same approach would be followed for the reference mission in preparation for dormancy. Once the crew occupies the vehicle following dormancy, a new plumbing line would be installed for urine collection. Therefore, no concerns exist related to the plumbing that contains untreated urine.

Pretreated Urine and Brine

As stated, urine collected on ISS is pretreated with chromium trioxide and sulfuric acid to provide microbial and chemical control. When concentrated by the Urine Processor Assembly during the distillation process, the sulfate (from the sulfuric acid) can precipitate with calcium from the urine to form calcium sulfate (gypsum). To allow 85% recovery of the pretreated urine, an alternate pretreatment is in development that would replace sulfuric acid with phosphoric acid. Therefore, both pretreatment solutions were considered in this assessment.

The urine is pretreated on ISS specifically to insure long-term microbial and chemical stability. Experience on ISS with the baseline pretreated (chromium trioxide and sulfuric acid) has shown excellent microbial control. Chemical precipitation has occurred, primarily when calcium sulfate was concentrated beyond its solubility limit, and also minor precipitation of organic residue that has not impacted operations of the Urine Processor. However, pretreated urine has not been maintained stagnant on ISS for more than a few months (when recovering from failed hardware), and ground experience has shown that microbial growth is more likely to occur in stagnant pretreat urine. In addition, chemical quality can shift during extended stagnant periods, potentially resulting in precipitation. These conditions can be exacerbated when the pretreated urine is exposed to air, which is the case in the urinal's phase separator, and in the Urine Processor's Distillation Assembly. Ground experience has shown that fungal growth will eventually occur at the air/liquid interface, even with urine pretreated with the chromium trioxide and inorganic acid.

There are two fundamental options for handling this section of the WRM during dormancy. The first option is to leave the pretreated urine in the plumbing without any off-nominal effort by the crew or systems design. This approach assumes the brine tank is emptied and refilled with fresh pretreated urine, and one UPA process cycle is completed to dilute the brine with pretreated urine and therefore minimize the potential for chemical precipitation during the dormant period. This approach would also assume the phase separator in the urinal would be replaced after dormancy, given the likelihood that microbial growth would be established in this hardware during dormancy. The second option would be to flush this section of the plumbing with water that has also been pretreated with chromium trioxide and the respective inorganic acid. This would be accomplished by flushing potable water down the urinal, either manually by the crew or by adding plumbing to support this capability. The water would be pretreated by the same process employed for pretreating the urine. Pretreated water would be used to fill the brine tank, followed by a process cycle to flush the brine loop. This procedure would likely require more effort by the crew, but would reduce the potential for chemical precipitation and microbial growth.

Since there is insufficient empirical data to determine if either of these methods would maintain microbial and chemical control during a dormant period, it was agreed to establish a parametric test program to evaluate the effectiveness of pretreated urine or the pretreated urine/water mixture. This test program will assess pretreated urine versus the urine/water mixture, and also look at the role of system pressure. The UPA Distillation Assembly is typically maintained at a vacuum pressure of 20 to 45 torr during Standby, which could be maintained during the dormant period. This would require the UPA to be powered throughout dormancy, however, so it is preferred to maintain the system at vacuum pressure. In addition, a test at ambient pressure is more representative of the conditions in the urinal's phase separator, which is another critical component to be evaluated. Table 1 provides a summary of the parametric test conditions.

Table 1. Test Matrix for Pretreated Urine Evaluation

| Tank Number | Test Fluid | Pressure |
|-------------|--|----------|
| 1-3 | Alternate Pretreatment | Ambient |
| 4-6 | Alternate Pretreatment/Water Mixture | Ambient |
| 7-9 | ISS Baseline Pretreatment | Ambient |
| 10-12 | ISS Baseline Pretreatment/Water Mixture | Ambient |
| 13-15 | Alternate Pretreatment | Vacuum |
| 16-18 | Alternate Pretreatment /Water Mixture | Vacuum |
| 19-21 | ISS Baseline Pretreatment | Vacuum |
| 22-24 | ISS Baseline Pretreatment /Water Mixture | Vacuum |

Urine Distillate and Humidity Condensate

The individual waste streams (urine distillate and humidity condensate) have unique issues because they each have established microbial growth, organic nutrients to support the establishment of a biofilm during dormancy, no biocide

to control microbial growth, and no current means to add biocide or flush the system. After 8 years of operation on ISS for the waste water bus, and 4 years of operation for the urine distillate plumbing, no obvious occlusion has occurred. However, the condensate collection system in the Russian segment has clogged on two occasions due to growth of a fungal mass, and it is likely a similar event will eventually occur in the US Segment. A 12 month dormancy period will only exacerbate this issue, requiring preventive measures to insure the operation of the water system.

One option for dormancy is to leave these waste lines stagnant, hoping that the biomass formation does not prevent system operation once the crew returns, or that the crew can recover the system by replacing plumbing that is occluded. Given the likelihood that significant biofilm growth occurs during dormancy, and the importance of quickly bringing the water system online after crew return, this option is not viable. The remaining options are to flush the lines with clean water such that biofilm growth is minimized to an acceptable level, add a biocide to maintain some level of microbial control, or to continually flow water through the plumbing throughout the dormant period. This last option could be accomplished in multiple configurations. For example, water could be evaporated in the air and continuously collected by the Condensing Heat Exchanger (CHX) and flushed through the waste water bus. If this concept presents too much system complexity, water could be plumbed from the potable bus to the inlet of the CHX's phase separator, allowing the CHX to remain dry during dormancy. For this option to be viable, the system must be designed such that there are no dead legs in the waste water bus. The obvious drawback to this approach is that the Water Processor would have to periodically operate during dormancy. If a hardware failure occurs without crew available to repair the system, the functionality of the system once the crew returns could be seriously compromised.

Urine distillate has a specific issue because it is generated in the condenser of the Distillation Assembly. This location provides limited access for introducing a biocide or flushing with water. Also, the condenser is a two-phase fluid region, which introduces a greater opportunity for microbial growth. Similarly, the plumbing that is used by the purge pump to maintain the system vacuum is another two-phase region, from the purge pump to the phase separator. Additional engineering analysis is required to identify the best approach for providing microbial control to these regions of the UPA during dormancy. Potential options include modifying the design of the DA and the purge pump to allow the condensate to be pumped dry in preparation for dormancy, or introducing an airborne disinfectant (e.g., ozone) that would disinfect the system for dormancy.

Humidity condensate has a similar issue as it is formed on the coating of the CHX, and then transferred as two phase flow to the phase separator. The ISS CHX is dried every 28 days to prevent the establishment of microbial growth. This is accomplished by simply raising the coolant temperature above the dew point. A similar approach can be applied for dormancy, but the line between the CHX and the phase separator will have to be flushed or a biocide will need to be introduced to maintain microbial control.

A final issue related to humidity condensate is the potential need during dormancy to operation the CHX. If the humidity levels in the cabin increase due to evaporation of water from the vehicle infrastructure, the CHX may be required to operate for a brief amount of time. If this is a credible scenario, any solution must be able to accommodate periodic operation of the CHX.

Water Processor Assembly (WPA) Waste Water

The WPA Waste Water tank is a specific problem because this tank currently employs a bellows tank on ISS that is known to harbor a significant fungal mass. This fungal mass will grow when the bellows are not regularly exercised, resulting in the release of biomass that can impact downstream hardware. Furthermore, the bellows maintains an ullage, such that the tank can never be actually emptied. This is obviously an issue for dormancy, since a significant fungal mass would be expected to grow in the waste tank during a 12-month stagnant period. Though it would be beneficial to simply replace the tank after dormancy, the mass and volume of the waste tank make this option not viable. A more credible option for addressing this issue is to use a biocide in the waste water for preventing growth of a biomass. This would likely have to be implemented for the duration of the mission, not just for the dormancy option, since introduction of a biocide to a tank with established biomass would likely result in the release of a significant quantity of biomass. Another option is to flush the tank with clean water multiple times to reduce the organic levels such that no significant biological growth can occur during dormancy. Another operational solution is to regularly flow water through the system during dormancy, either by introducing water vapor to the cabin and operating the condensing heat exchanger, or by circulating water from the potable bus to the waste bus, and then processing the water through the WPA. Finally, a design solution is to replace the bellows tank with a bladder concept, such that the tank could be completely emptied prior to dormancy. This would reduce microbial growth by eliminating the bellows,

though biofilm would still likely be present along the bladder surface. This would also require a system design modification to transfer waste water from the waste tank, which currently uses the spring force of the bellows to push fluid downstream.

Waste water from the waste tank is further processed by a phase separator (to remove residual free gas) and then pumped by a gear pump to a particulate filter. This section of the WPA will take advantage of the process employed to protect the waste tank (addition of a biocide or periodic flushing). Note that the phase separator will maintain a gas/liquid phase during dormancy, therefore this item is also more likely to grow a microbial biofilm during the dormant period.

WPA Process Water

This region is a small section from the effluent of the particulate filter to the inlet of the Catalytic Reactor. Though the WPA process water has an established microbial population, the particulate filter has removed all solids greater than 0.5 microns and organic contaminants have been reduced somewhat by the first Multifiltration Bed. Therefore, the potential for biofilm growth has been reduced compared to the waste water. However, there will still be a sufficient microbial population coupled with the organic content of the waste water to support growth of biofilm. Specifically, the MF Beds will likely grow a microbial biofilm during stagnation, given the organics that will be present on both the adsorbent and the ion exchange resin. Periodic operation of the WPA (especially if clean water is used) would reduce the risk, though the preferred solution may be to install fresh MF Beds after each dormant period. This would require that the MF Beds be designed to last for the duration of the crewed mission, to minimize wasted resupply mass due to replacement of MF Beds after dormancy.

WPA Reject Line

The Reject Line allows product water to be recirculated from the product line back to the waste tank. This occurs for one hour at the beginning of each process cycle, allowing the leachates from the Ion Exchange Bed to be flushed out, and giving the Catalytic Reactor sufficient time to become thermally stable. In addition, this line is used to reject product water back to the waste tank any time the WPA instrumentation detects an anomaly that indicates product water quality may not meet potable standards. On ISS, a Microbial Check Valve (MCV) is used to prevent microbial species from migrating from the waste water to the product water. For the reference mission, this hardware will have to be replaced with a similar concept implementing the silver biocide. Furthermore, analysis must be performed to determine if this line can effectively prevent microbial migration into the potable bus during the dormant period, or if additional measures (for example, an isolation valve) are required to insure this does not happen.

Potable Water

This region begins at the Catalytic Reactor, which operates at 267 F on ISS to maintain a sterile barrier between the process water and the potable water. Downstream of the Catalytic Reactor, a biocide is added to provide additional microbial control. On ISS, iodine is used as the biocide. However, the plan is to transition to silver for future manned missions, since iodine must be removed prior to crew consumption. In either case, there is an issue with the stability of the biocide, in that the biocide tends to decrease in concentration over time. Silver tends to plate to metal surfaces, which would leave the potable water without a biocide to mitigate microbial growth. Currently, personnel at the Johnson Space Center (JSC) are developing silver as a biocide for future manned missions, including techniques for adding silver and preventing or minimizing loss of silver to metal surfaces.

WPA Potable Lines: It is recommended to keep the reactor at its operating temperature during dormancy to maintain the sterile barrier between the waste and potable water. If this is not viable, then the reactor will be designed such that the crew can physically isolate (either by an isolation valve or by disconnecting the plumbing) the line to prevent microbial growth into the potable region. The region between the reactor and the location at which the silver biocide is added will be product water but with no biocide. The residual volume of this region will be minimized, but no additional operation controls should be required. Given the low organic content and relative absence of microbial population prior to dormancy, there is no credible risk of significant microbial growth. Once system operation is established, this section will be flushed per nominal WPA operation (recirculating sterile water from the reactor back to the WPA waste tank through the Reject Line) to insure it is adequately clean for further processing.

WPA Product Tank: The WPA fills the product water tank at the completion of the treatment process. For the reference mission, this water would presumably possess a low microbial content. On ISS, no microbial contamination

has been detected after 4 years of operation, and a similar process (design, hardware delivery, and operation) will be employed for the reference mission. The water system will be designed to maintain a low organic content, thus minimizing the risk of significant microbial growth. Finally, a silver biocide will be used to insure microbial control throughout the mission. Since silver will plate out during dormancy with the existing tank materials, there are three options for addressing the product tank for dormancy:

- 1) If technology development results in the delivery of materials or coatings that prevent plating of silver, then no additional measures will be required to sustain the potable tank during dormancy. Periodic operation of the Product Tank to support operational concepts in which the WPA is periodically used to process water will only benefit the microbial integrity of the Product Tank by replenishing silver concentrations.
- 2) Significant discussion has occurred in the previous years related to the necessity of a biocide to maintain microbial control during dormancy, assuming the hardware and water is properly sterilized initially and maintained during operation, and a low organic content is maintained. This discussion has primarily been driven by the Orion vehicle, which will use stored potable water to supply the crew with drinking water. Test results have shown that the microbial content is maintained at or near sterile conditions if these conditions are held. Based on this premise, the WPA product tank will not require any additional design or operational controls during dormancy even if no measures are put in place to prevent plating of the silver. As with the previous option, periodic operation of the WPA would serve to replenish the silver biocide.
- 3) If analyses indicated that maintaining a viable silver concentration in the potable tank is required, and efforts to develop a coating or other means to prevent silver plating, then the remaining option is to periodically operate the WPA as required to maintain a viable silver concentration in the product tank.

Since chemical leachates do tend to accumulate in the potable water during extended storage periods (for example, nickel from Inconel bellows), it is likely that the Product tank will need to be drained and filled after the dormant period to establish potable limits for inorganic leachates.

Potable Distribution Bus

This bus delivers water from the WPA to the various use points, including the urinal, Potable Water Dispenser (PWD), Oxygen Generation System (OGS), and the Total Organic Carbon Analyzer (TOCA). As with the Product Tank, two issues with dormancy are silver plating out on the metal surfaces and introduction of inorganic leachates from the metal tubing. Options for addressing these issues are as follows:

Potable Bus Options:

- 1) Design the potable bus such that potable water can be recirculated periodically (or continuously) during the dormant period. Hardware would be included in the bus for maintaining the silver concentration to insure the biocidal level is maintained. To support this architectural concept, it is important to eliminate dead legs in the bus that would be isolated in a recirculating system. Since each use point will effectively be a dead leg, specific design or operational approaches will be required for each to insure the transition from dormancy to nominal operations is successful. Finally, inorganic leachates may be removed with an Ion Exchange Bed, or the contents of the bus could be flushed back to the waste bus once the crew returns to establish potable standards for the inorganic contaminants.
- 2) Drain the water from the potable distribution bus and purge with dry air. This approach would effectively eliminate microbial growth and the introduction of leachates, but is probably not viable due to the significant operational impacts.

- 3) Leave the bus stagnant for the duration of the dormant period, relying on the same measures as the product tank to maintain microbial control (low microbial population, low organic content, and coatings if available to prevent silver plating). After dormancy, flush the contents of the potable bus back to the waste bus, and replenish the potable bus with water produced by the WPA.
- 4) Leave the bus stagnant for the duration of the dormant period, and provide the capability to recover the potable bus from microbial growth after the crew returns. Recovery from microbial upset could be achieved by flushing the bus with water that has an elevated silver concentration, flushing the bus with an alternate biocide (such as ozone or peroxide, assuming microbial contamination has some level of silver resistance), or performing thermal sterilization.

1. Urinal

The potable bus supplies flush water to the urinal. Since maintaining water quality is not critical for this system, the primary concern is preventing back flow of microbial growth from the urinal into the potable bus during dormancy, and minimizing the length of the dead leg to the urinal.

2. Potable Water Dispenser (PWD)

The PWD supplies water to the crew for drinking and food preparation. On ISS, the PWD removes iodine to prevent potential medical issues with the crew. The PWD had initial issues with microbial contamination due to the absence of a biocide and inadequate hardware disinfection during processing on the ground. This issue was resolved by shocking the water with iodinated water (at 30 mg/L), and mandating additional microbial controls if PWD is not used for up to 3 days. These measures were based on the assertion that frequent use of the PWD would mitigate microbial growth, specifically the levels observed as PWD was initially brought online on ISS. This hardware experience on ISS applies to the dormancy assessment, in that consistent (i.e., daily) use of a water system provides mitigation against microbial upset. Conversely, it is logical to conclude a dormant system will be more apt to establish microbial growth, especially when a) microbial contamination is already present, and b) there is no residual biocide in the water. Based on this rationale, the PWD for future missions will be less susceptible to microbial upset due to the use of a biocide that does not have to be removed from the water prior to crew consumption, and improved processes for disinfecting hardware prior to launch.

Despite these improvements, there remain specific issues with the PWD that require active measures to protect the hardware and the potable bus from microbial contamination. One primary concern is the dispensing needle that the crew accesses for drinking water and food preparation. This needle is an easy source of back-contamination from the user into the PWD. The second issue is the fact that the PWD would be a significant dead leg off the potable bus, and would be difficult to maintain microbial control given the current hardware design.

PWD Options:

- 1) Remove the dispensing needle prior to dormancy to mitigate risk of microbial back-contamination. This task would apply to all options for addressing PWD during dormancy.
- 2) Redesign the PWD to a simpler concept that can be more easily managed for dormancy. A preferred option is to implement only a dispensing needle for the PWD, which can be jumpered out of the potable bus prior to dormancy. When the crew returns, a new needle is installed for crew use.
- 3) Leave the PWD design effectively unchanged, and simply flush the system when the crew returns until acceptable microbial concentrations can be achieved. This approach has significant risk given the possibility that the system cannot be adequately recovered.
- 4) Modify the PWD design to provide means to recover microbial control after dormancy. For example, deliver a system that can be readily flushed with an alternate biocide or the thermally disinfected to recovery from microbial growth.

3. *Oxygen Generation System (OGS)*

The OGS converts water to oxygen and hydrogen gases. The O₂ is vented to the cabin, and the H₂ is either transferred to the CO₂ Reduction System (Sabatier) or vented to space. On ISS, the water provided to OGS initially passes through an Ion Exchange Bed to remove the residual iodine. The same process would be required for removal of silver, since the cell stack would be poisoned by either biocide. Therefore, the OGS hardware downstream of the Ion Exchange Bed would not have a biocide and would therefore be more likely to experience microbial growth. Microbial growth on ISS has not been a significant concern, partially due to the relatively low organic carbon content in the OGS recirculation loop, and the fact that the water in the loop is almost continuously circulated.

OGS Options:

- 1) Continue to flow water through the recirculation loop throughout dormancy. This operation requires the cell stack to be powered at a minimal level, though a low level electrolysis reaction will occur that requires periodic replenishment of water to the loop. This could be achieved by requiring the WPA to continue to provide water to the OGS during dormancy.
- 2) Leave the OGS unpowered during dormancy, but perform specific procedures to flush the recirculation loop prior to dormancy to reduce the organic content to the lowest possible level. Though a biocide is not present, the low organic content may be sufficient to control microbial growth. This option has significant risk of microbial growth to the extent that the OGS would not be operational once the crew returns after the dormant period.
- 3) Leave the OGS unpowered during dormancy, but perform specific procedures to flush the recirculation loop prior to dormancy to reduce the organic content to the lowest possible level. In addition, add a biocide to the loop that is compatible with the cell stack. This option requires the identification of a biocide that is compatible with the cell stack, which would require a significant materials compatibility effort between various biocides and the materials in the OGS recirculation loop.

4. *TOC Analyzer*

On ISS, the TOCA receives sample water either directly from the WPA or via a sample bag from the PWD. Since this product water maintains a relatively low organic content, the microbial population in the TOCA is expected to be low. More importantly, the TOCA analytical method includes forming an oxidant (ozone and peroxide) which would also serve as a disinfectant against microbial growth. Therefore, the TOCA system is expected to be robust against microbial operation during nominal operation. Since the TOCA can be configured prior to dormancy in a manner that insures relatively low organic and microbial content, there is minimal risk of any significant microbial growth that would prevent operation after dormancy. Any microbial growth that did occur during dormancy could be addressed by operating the loop with the oxidant for sufficient time to achieve disinfection. Note that additional measures (e.g., recalibration or replacement of parts) may be required for TOCA to meet performance requirements after one year of dormancy, and these will be defined in the final report for the dormancy assessment.

IV. **Pre-Treated Urine Dormancy Test**

In order to study the effects of long-term storage of pre-treated urine under dormancy conditions, a test was initiated in 2013 to simulate those conditions and observe the results over a one-year period.

A. **Test Description**

Twenty four transparent acrylic tanks were filled with a quantity of pretreated urine and a bent length of stainless steel tubing. These were then placed within two freestanding metal cabinets and allowed to sit in darkness with a minimum of disturbance for a period of one year. Daily, they were inspected and any changes noted. Weekly, they were photographed to allow detection of longer term changes. At the end of one year, the tanks were opened and samples were taken of the pretreated urine while the tubes were inspected.

1. **Acrylic Tanks**

Two types of acrylic tank were constructed. The first type was intended to rest at ambient pressure, and so was built as a simple cylinder with a flat plate on either end. The upper plate was removable and sealed with O-rings. The second type was to rest at 25 inches of vacuum, and so had the additional features of a vacuum pressure gauge and a hose, valve, and fittings to allow it to be attached to a vacuum pump as needed to pull the pressure back down in the event of air leakage into the tank. Tank designs are evident in photographs present later in this report.

A total of 24 tanks were used, twelve at ambient pressure and twelve more at vacuum. Each had an internal volume of 3.77 liters.

2. Urine Pretreatment Solutions

Two different pretreatment solutions were prepared. One included the “baseline” pretreatment stabilizer, a formulation of chromium trioxide and sulfuric acid. The other used the “alternate” stabilizer, which contained chromium trioxide and phosphoric acid. In addition, a solution of several organic chemicals were added, along with three dry chemicals, to mimic biological constituents present in urine generated on the ISS and absent in those concentrations on Earth. See Table 2 for lists of these chemicals and their concentrations.

Table 2: Ersatz Formulations

| Urine Pretreatment (mL/L of urine) | |
|------------------------------------|--------|
| Organic Concentrate | 75.77 |
| DI flush water | 189.23 |
| Stabilizer | |
| Baseline | 15.9 |
| OR | |
| Alternate | 17.5 |

| Organic Concentrate Recipe (g/L of Concentrate) | |
|---|---------|
| Urea | 44.775 |
| Taurine | 3.0989 |
| Creatinine | 5.6519 |
| Histidine | 10.7973 |
| Glycine | 5.7664 |
| Glutamine | 6.232 |
| Citric Acid | 2.329 |
| Glucuronic Acid | 0.4368 |
| Serine | 2.4966 |
| Alanine | 2.4846 |

| Baseline Stabilizer Recipe (g/L of urine) | |
|---|-----|
| CrO ₃ | 90 |
| DI Water | 545 |
| H ₂ SO ₄ | 365 |

| Alternate Oxidizer (g/L) | |
|--------------------------|-----|
| CrO ₃ | 300 |
| DI Water | 700 |

| Alternate Stabilizer (mL) | |
|--------------------------------|-------|
| Alternate Oxidizer | 284.8 |
| H ₃ PO ₄ | 715.2 |

An amount of each of these solutions was prepared adequate to fill six acrylic tanks: three ambient pressure tanks and three vacuum tanks. Each tank received 1500 mL of liquid.

Next, additional quantities of both pretreat solutions were prepared and diluted on a 1:1 basis, by volume, with deionized water. The total volumes of these diluted solutions were equal to the fully-concentrated solutions. The dilute solutions were also used to fill three ambient acrylic tanks and three vacuum tanks each with 1500 mL.

The filled acrylic tanks were placed inside two metal cabinets which were themselves located away from other activities to minimize external disturbances. The left cabinet contained the ambient tanks, while the right cabinet held the vacuum tanks as well as a vacuum pump stored in its base for exclusive use during the test. Four tanks were placed

on each of the three shelves in each cabinet, with tanks containing the same solution residing in the same relative position in each cabinet. The tanks were numbered as shown in Figure 2 below.

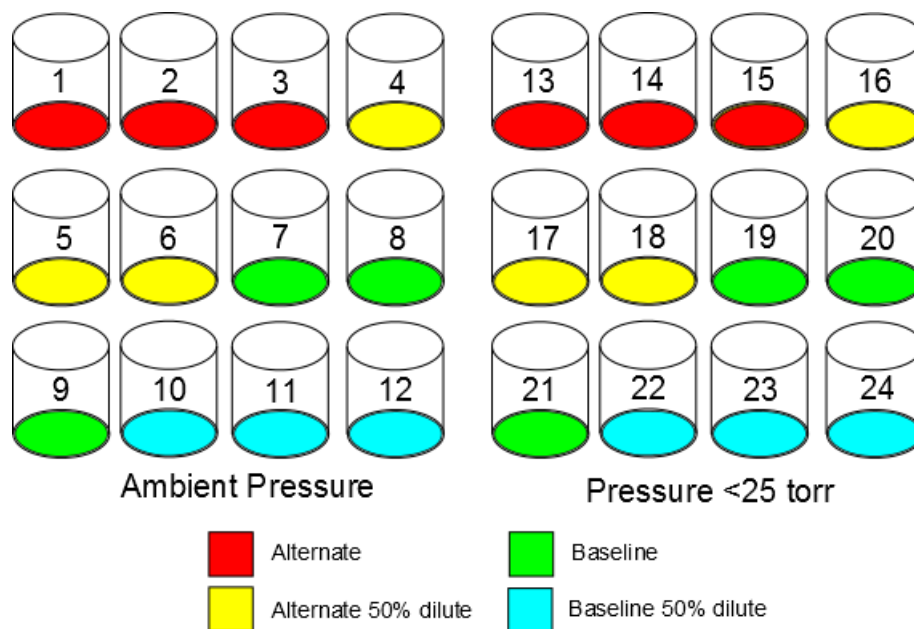


Figure 2: Dormancy Tank Configuration

The doors of the cabinets were kept closed at all times except during daily observation and weekly photography, which were both performed as quickly as feasible. Care was taken to alert nearby people not to jostle or open the cabinets.

B. Test Activity

1. Daily Observation

Every afternoon, Monday through Friday, the cabinet doors were opened and the urine in the tanks observed. Any changes, including but not limited to color, turbidity, or fluid level, were noted. In particular, colonies of microbial growth were sought. Any significant change was photographed and reported to the test engineer immediately.

Also, the pressure inside each of the vacuum tanks was recorded. If the pressure had risen above 25 psig of vacuum, then the pump was attached and the vacuum drawn back down to an appropriate level.

2. Weekly Photographs

On Friday afternoons, each of the tanks was photographed using a digital camera, both as a form of record-keeping and a way to identify long-term changes too subtle for daily observation to spot.

3. Post-Dormancy Samples

At the end of one calendar year, each tank was removed from the cabinets and opened. The liquid was portioned out into a series of sample vials. Any solids that had grown were likewise collected. The stainless steel tubes were inspected for discoloration, pitting, or other evidence of reaction to the acidic solution.

C. Test Results

Testing began on March 29, 2013 with the addition of the pretreatment solutions to the acrylic tanks, and continued for 365 days until March 28, 2014. Samples were taken the following Monday, March 31, 2014. There were no observations between October 1, 2013 and October 16, 2013, due to the temporary government shutdown at that time, nor on several dates from late November through Early January due to personnel workload. It does not appear that any significant events were missed due to these lapses.

1. Observations

Data collection over the course of the test was largely in the form of qualitative observations made by a single observer. This gave the observer the greatest chance of spotting any change from one day to the next. In late November, duties were passed temporarily to an alternate observer until early January, when the original observer resumed the duty.

The vacuum pressure inside the appropriate tanks was also recorded daily, to determine if the tanks with higher or more consistent vacuum responded differently from those closer to the minimum limit or with more unstable levels. Observations were made on Monday through Friday and recorded in an Excel spreadsheet.

a. Starting Appearance

On Day One of the test, the tanks were filled and placed within their cabinets. They were photographed in place as the baseline appearance against which future changes would be measured. Observation began on Day Four, at which point Tanks 1 through 10, 13 through 15, and 17 through 21 were uniformly “dark green, clear, half full, pipes clean.” Tanks 11, 12, 16, and 22 through 24 were, “dark brownish green, clear, half full, pipes clean.” “Clear,” in this context, refers to the transparency/turbidity of the liquid. Various inconsequential bubbles or condensate fog also appeared in most tanks.

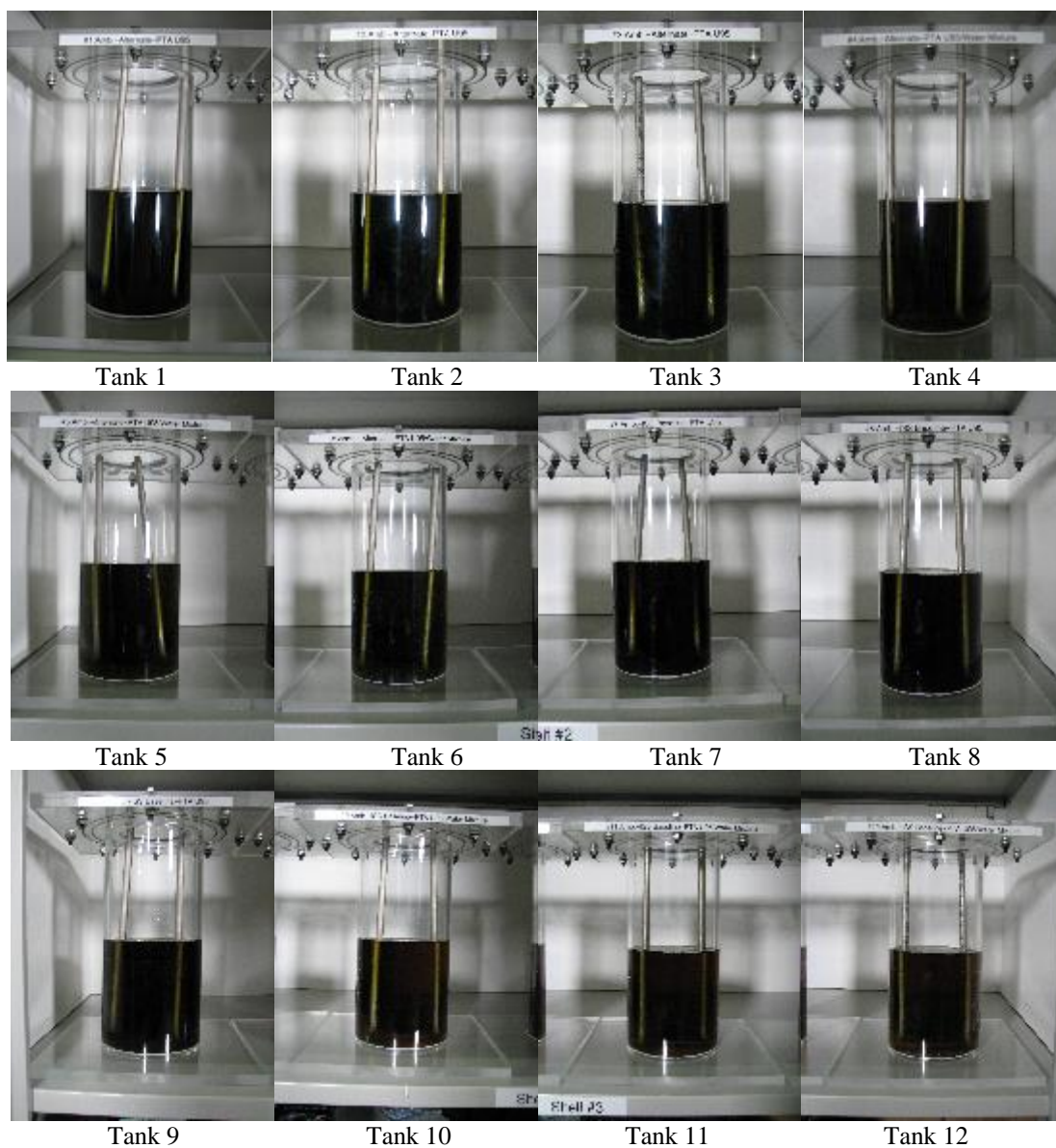


Figure 3. Day One Photos: Ambient Pressure Tanks 1-12

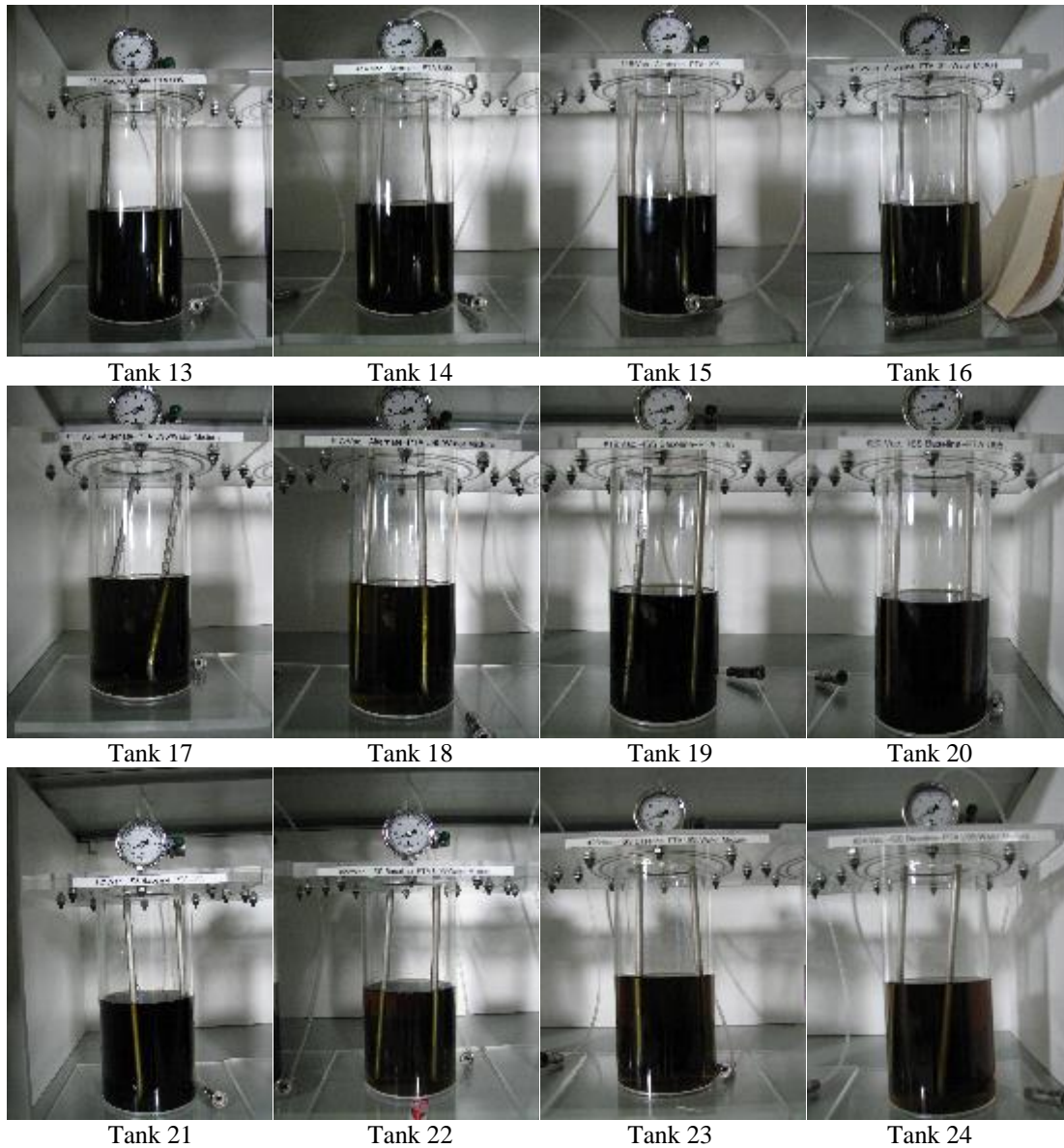


Figure 4. Day One Photos: Vacuum Tanks 13-24

b. Calendar of Significant Events

On Day 6, Tank 23's vacuum pressure dropped to less than 26, requiring the use of the pump to return the tank to the required vacuum. This was the first instance of a problem that persisted throughout the test: Tank 23 needed depressurization at least once per week, indicating a fault in the seal, a total of 50 times over the course of the test. In contrast, most of the other tanks only required this action a single-digit number of times in the entire year. See Figure 5.

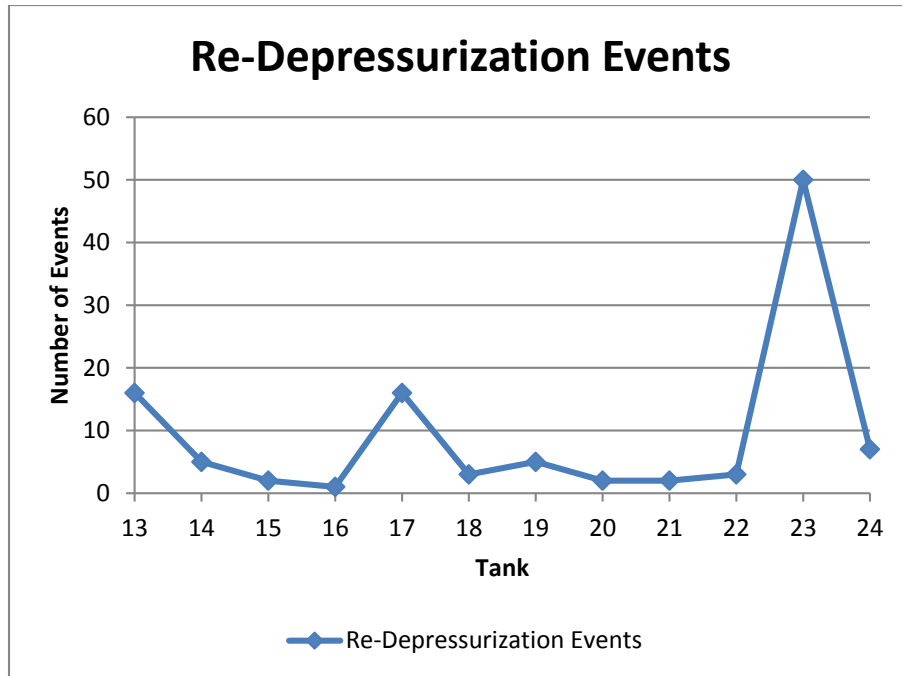


Figure 5. Number of Depressurization Events

On April 19, 2013, Day 22, condensation was observed on the inner surface of all 24 tanks, above the waterline. The day was particularly cold and wet outside, so it was hypothesized that the temperature dropped below the dew point inside the tanks. The effect was photographed and care was taken to keep note of it in future, in case it had an effect. The fogging occurred repeatedly on particularly cold or wet days.

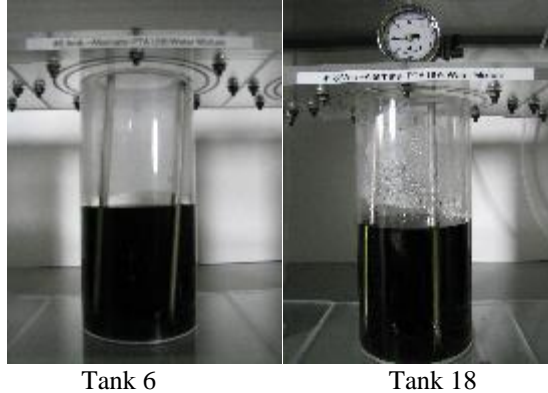


Figure 6. Representative Condensation Inside Tanks, Ambient and Vacuum

On Day 7, liquid level lines were marked on the exterior of each tank. On Day 26, April 3, 2013, it was observed that the fluid level in each tank appeared lower than these marks. The difference was slight enough that the observer was unsure whether the levels had actually decreased, or the marks were placed with insufficient precision. Close-up photos of the marks were not available for comparison. Given that the apparent drop occurred in all tanks, both ambient and vacuum, the possibility of evaporative leakage seemed unlikely. It was decided to continue to monitor the liquid levels to determine if the decrease continued. The only other mention of dropping liquid levels was on Day 151, August 26, 2013, only for the ambient tanks, and barely noticeable. The total drop over the course of the test was on the order of 1/16", within the margin of error for the original mark placement. The test operator did not believe that the interior of the tanks was communicating with the environment in any significant way.

On May 8, Day 41, the first evidence of fungal growth was spotted in Tank 10, which contained the baseline stabilizer mixed 50/50 with water. It appeared as white fuzz on one upright of the metal tube roughly half an inch above the waterline. See Figure 7. On Day 49 a second colony appeared on the wall of the acrylic tube at the waterline, near but unconnected to the growth on the pipe, which had continued to grow downward until it also reached the liquid. Both continued to grow slowly over the next weeks. On Day 77 it was noted that the growth was spreading across the surface of the liquid but not down into it. As they continued to spread over the following weeks, they became thinner and more brown, with an increasingly dull white infrastructure resembling the exposed roots of a tree. By Day 130, the growth had stabilized, neither growing nor shrinking at any later point in the test.

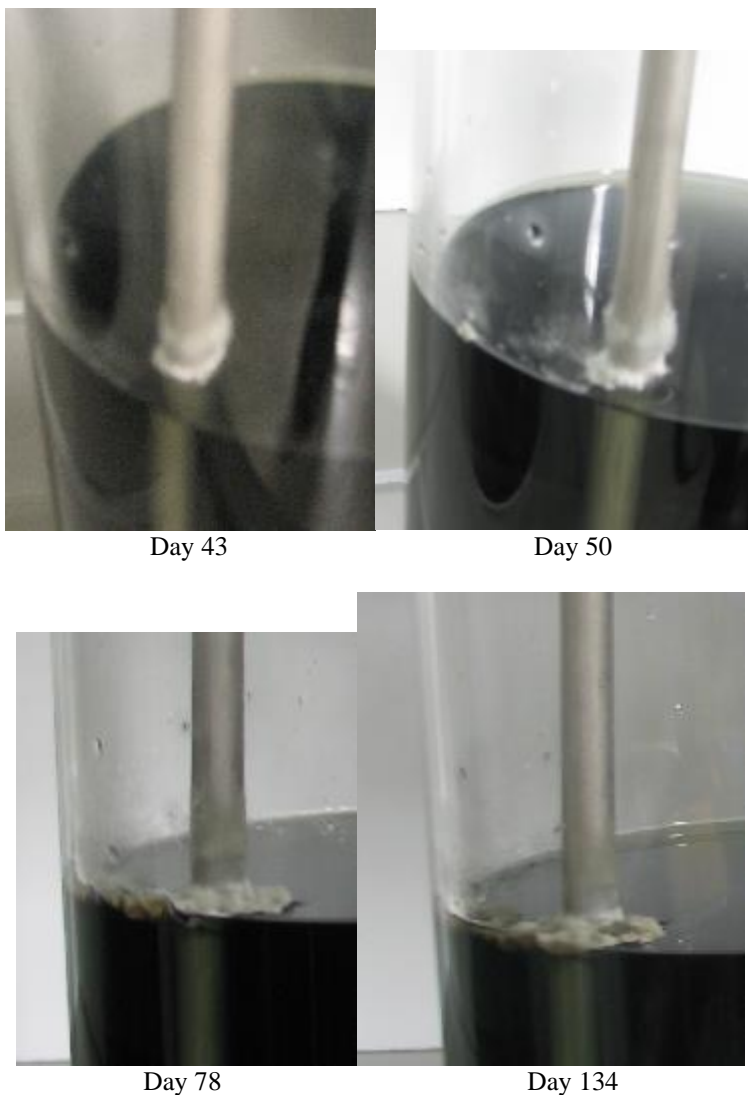
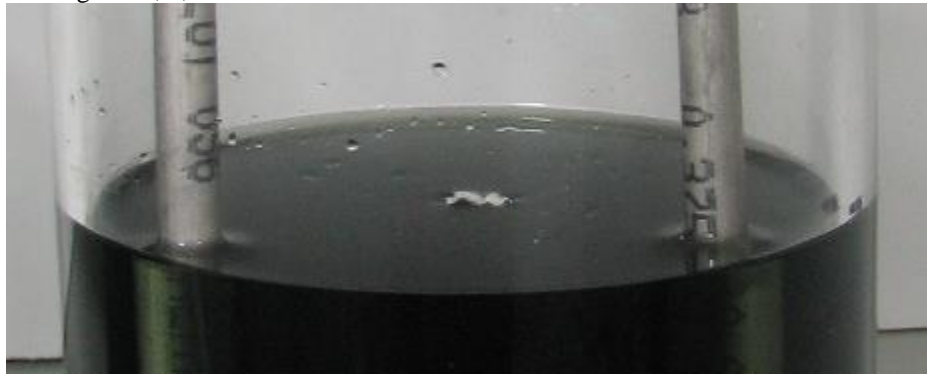


Figure 7. Fungal Growth in Tank 10

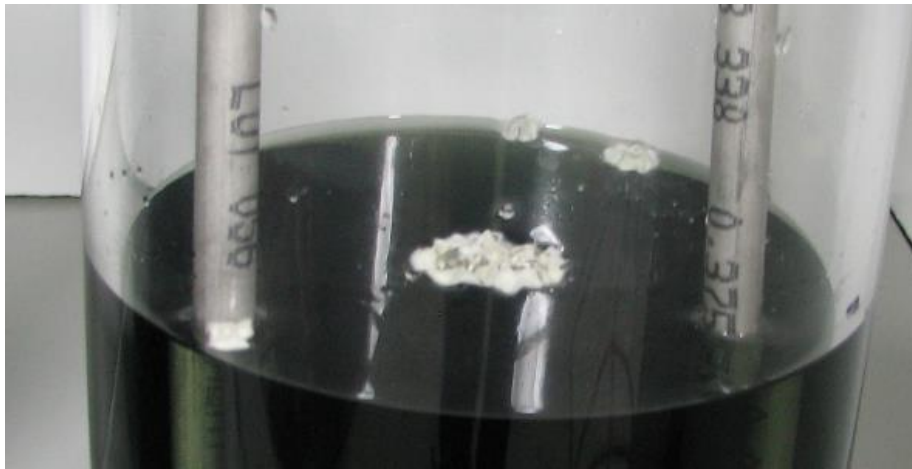
Later, on Day 159, similar growths started appearing free-floating in Tank 12, moving toward each other at the center of the tank as they grew. On Day 165, growths were also identified at the bottom of Tank 12. Photography failed to capture images of these growths. Multiple colonies formed over the following weeks, growing and moving. The last mention in the log of the fungus growing was on Day 203, but the colonies continued to float about. On day 291 the

log uncertainly questions the growth of two of the smaller colonies, marking the last observation recorded until the end of the test. See Figures 8, 9, and 10.



Day 162

Figure 8. Fungal Growth in Tank 12



Day 203

Figure 9. Fungal Growth in Tank 12



Day 299

Figure 10. Fungal Growth in Tank 12

Tank 11, sharing the same solution as Tanks 10 and 12, never evidenced any such growths.

Meanwhile, on Day 186, Tanks 13, 14, and 15 presented what appeared to be “oil slicks” on the surface of the fluid. They each had that rainbow-like sheen, as shown in Figure 11 below. It might possibly have been a film or membrane grown across the liquid surface; it would be impossible to tell until the tanks were opened at the end of the test. These three tanks all contained the same solution: alternate pretreated urine without dilution. They were also all held at reduced pressure. A quick investigation determined that the test apparatus, including valves, tubing, QD’s, and pump, did not use oil in any way that could have introduced it into the tank during a re-depressurization. Besides which, it had been months since the last time Tanks 14 or 15 had required depressurization, and two weeks for Tank 13. The films had appeared in all three tanks on the same day. Also, none of the other tanks exhibited a film at that time. External contamination during the test seemed unlikely.

Coincidentally, these appeared the day before the government shutdown of 2013, preventing immediate observation of subsequent events.

Upon returning on Day 203, a film had become visible in Tank 2, and possibly in Tank 3, while the films in Tanks 13 through 15 had started breaking into multiple sections. Note that Tanks 2 and 3 held the same solution as Tanks 13-15. These did not change again during the test.

Tanks 17 and 18 exhibited films as of Day 327, but they were not visible on Day 333 and did not reappear until Day 357.

Upon closer inspection at the end of the test, when the tanks were opened for sampling, the following tanks each had a film upon the liquid surface: 1, 2, 3, 13, 14, 15, 17, and 18. Tank 1 was slight enough to avoid prior observation.



Figure 11. Representative “Oil Slick”—Tank 13, Day 203

At the end of the test, a final set of observations and photographs were made before sampling began. See Table 3 for a comparison of initial and final observations of each tank.

D. Sample Results

Following 365 days of dormancy, the tanks were opened and the fluids sampled in accordance with procedure. Only a portion of the analytes tested for were detected either before the start of the dormancy period, after the end of the period, or both. Those are listed in Table 4. Parameters of particular interest are discussed below, with accompanying data plots in Figures 12 through 21.

Table 3. Test Log—Day 1 vs. Day 365

| Tank | Day 1 | Day 365 |
|-------------|--|---|
| 1 | dark green, clear, half full, pipes clean, bubbles on pipes under surface, pipe in contact w/ wall | Very dark green. "Oily" surface. Hard to see into depths. |
| 2 | dark green, clear, half full, pipes clean, bubbles on pipes under surface | Same as 1 |
| 3 | dark green, clear, half full, pipes clean, bubbles on pipes under surface | Same as 1 |

| | | |
|----|--|---|
| 4 | dark green, clear, half full, pipes clean, bubbles on pipes under surface, pipe in contact w/ wall | Dark. Slightly translucent, not very green. |
| 5 | dark green, clear, half full, pipes clean, bubbles on pipes under surface, pipes not parallel | As 4, but more green. |
| 6 | dark green, clear, half full, pipes clean, bubbles on pipes under surface | As 4 & 5, green-tint between 4 & 5. |
| 7 | dark green, clear, half full, pipes clean, bubbles on pipes under surface, pipes not parallel | Dark, greenish, somewhat translucent but can't see all the way through. |
| 8 | dark green, clear, half full, pipes clean, bubbles on pipes under surface, pipes not parallel | Darker than 7, less visual depth, less green |
| 9 | dark green, clear, half full, pipes clean, bubbles on pipes under surface | Dark, more green than 7 or 8, same visual depth |
| 10 | dark green, clear, half full, pipes clean, bubbles on pipes under surface | Dark, but less than 7-9. less green. Growths on left upright unchanged in months |
| 11 | dark brownish green, clear, half full, pipes clean, bubbles on pipes under surface | As 10, but not growths |
| 12 | dark brownish green, clear, half full, pipes clean, bubbles on pipes under surface | Mostly clear, lightly green-tinged, translucent. Growths on surface and at bottom below left upright, unchanged for long time |
| 13 | dark green, half full, pipes clean, 27 inHg | 26.625. Dark green. Oily surface, shallow translucence |
| 14 | dark green, half full, pipes clean, 26.5 inHg | 26.5. Same as 13 |
| 15 | dark green, half full, pipes clean, 27 inHg, droplets on air-contact surface | 27.125. same as 13 & 14 |
| 16 | dark brownish green, half full, pipes clean, 28 inHg | 27.375. More translucent, less intensely green than 13-15. |
| 17 | dark green, half full, pipes clean, 26.5 inHg, slight condensate | 26. Light oil slick. Otherwise like 16 |
| 18 | dark green, half full, pipes clean, 26.75 inHg, slight condensate | 27.375. Like 17 in all respect. |
| 19 | dark green, half full, pipes clean, 26.5 inHg, slight condensate | 26.5. Dark. Not very green. Largely opaque |
| 20 | dark green, half full, pipes clean, 27 inHg, slight condensate | 27.125. Like 19 but greener. |
| 21 | dark green, half full, pipes clean, 27 inHg, slight condensate | 26.875. Like 19. |
| 22 | dark brownish green, half full, pipes clean, 27 inHg, slight condensate | 27.625. Dark, almost no green. Most opaque PT/water mix. |
| 23 | dark brownish green, half full, pipes clean, 26.5 inHg, slight condensate | 25.875 press to 28+. Greener than 22. Otherwise the same. |
| 24 | dark brownish green, half full, pipes clean, 28.5 inHg, slight condensate | 28.25. Greener than 23. Otherwise same. |

Table 4. Detected Chemical Analytes

| Group | Parameter |
|---|--|
| Acid Extractables-EPA 625 List | 4-Methylphenol Phenol |
| Alcohols/Acetone (Direct Injection GC/MS) | Ethanol Methanol |
| Apparent Biomass | Total Fungal |
| Conductivity | Conductivity |
| Inorganics | Aluminum Calcium Chromium Copper Iron Lead Magnesium Nickel Phosphate (as P) Potassium Selenium Sodium Total Sulfur Zinc |
| Non-volatiles (LC/UV-VIS) | Urea |
| Organics/Acid-Extract | 4-Methylphenol Phenol |
| Organics/Neutral-Extract | Dibutylphthalate |
| Organics/Non-Volatiles | Urea |
| Organics/Semi-Volatiles | (+)-Neomenthol 2-Phenylacetic acid Benzaldehyde Benzoic acid Caffeine Dibutylphthalate gamma-Hexalactone Ibuprofen Methyl sulfone Nicotine Oxindole Palmitic acid Phenol Salicylic acid Thymol Vanillin |

| | |
|---------------------------------|--|
| Organics/Volatiles/Non-target | Acetaldehyde |
| Organics/Volatiles | 2-Butanone (Methyl ethyl ketone) Acetone |
| Organics-Alcohols-Acetone | Ethanol Methanol |
| ORP | Oxidation Reduction Potential |
| pH | pH |
| Semi-volatiles (GC/MS) | (+)-Neomenthol 2-Methyl butyric acid 2-Phenylacetic acid Benzoic acid Caffeine Ibuprofen Methyl sulfone Nicotine Oxindole Palmitic acid Phenol Salicylic acid Vanillin |
| Solids | SG TDS TSS |
| Special | Constituency of brown coloration on titanium tube |
| Special | Constituency of green coloration on titanium tube |
| TOC | NPOC TIC |
| Total Microbial | Total Bacterial Total Fungal |
| Volatiles - Non-Targets (GC/MS) | Acetaldehyde Methyl disulfide |
| Volatiles (P&T/GC/MS) | 2-Butanone (Methyl ethyl ketone) Acetone Methyl methacrylate |

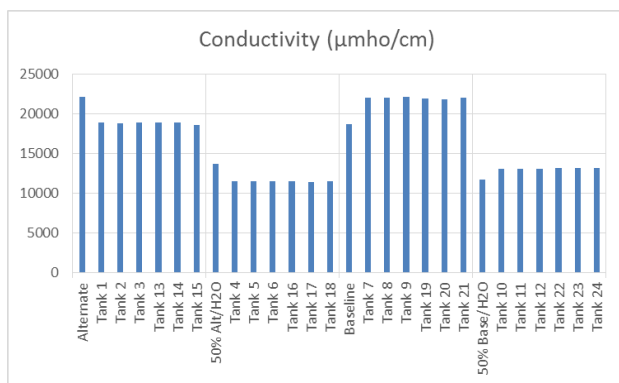


Fig. 12. The alternate pretreatment reduced the conductivity of all solutions by roughly 300 µmho/cm. The baseline pretreatment allowed it to rise 100-300 µmho/cm.

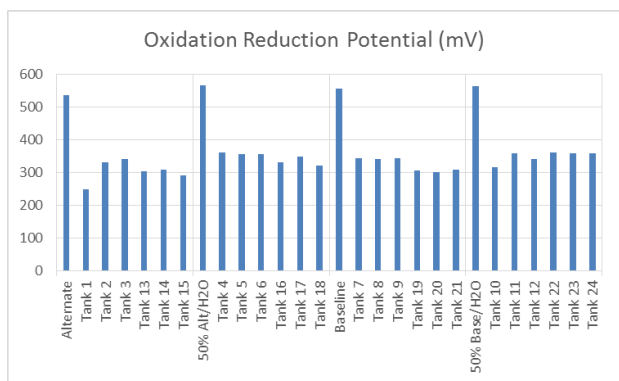


Fig. 13. The ORP of all solutions under all conditions reduced by roughly 60%, the alternate ambient high-concentration solution being the most effective by a small margin.

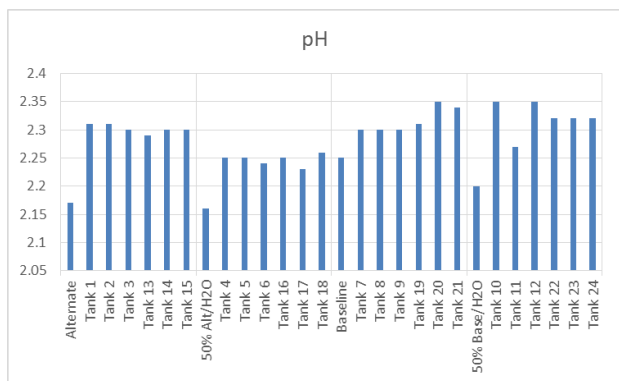


Fig.14. The pH of all solutions rose only slightly, remaining in the low-2 range throughout the test year and therefore maintaining the acidity needed as a biocide.

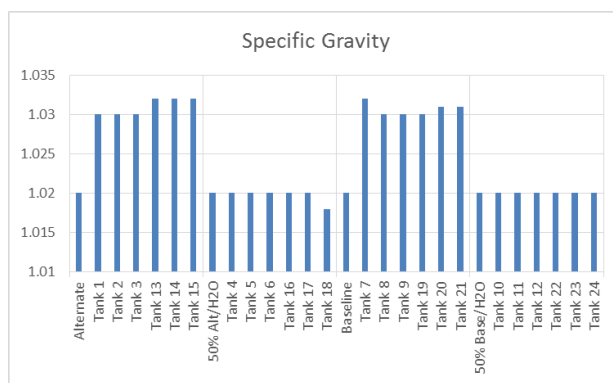


Fig. 15. The specific gravity of all solutions remained nearly constant over the course of the year, within a few hundredths of the starting value. The 50% diluted solutions were better at keeping this consistency than the full-concentration solutions.

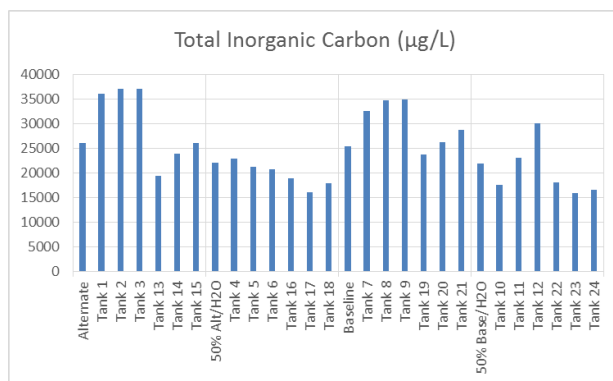


Fig. 16. In all cases, the fluids held under vacuum ended the test with a lower TIC than the corresponding ambient-pressure fluids. Both alternate solutions and the dilute baseline solution in the vacuum tanks ended with TICs lower than or equal to the starting values. Among the ambient tanks, this can only be said for Tanks 5, 6, and 10.

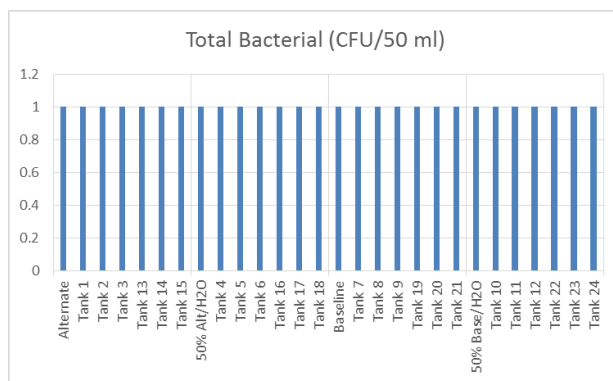


Fig.17. Neither at the beginning nor the end of the test period did any of the fluids exhibit bacterial growth, evidence that the pretreatment solutions are an effective biocide for at least a year of dormancy.

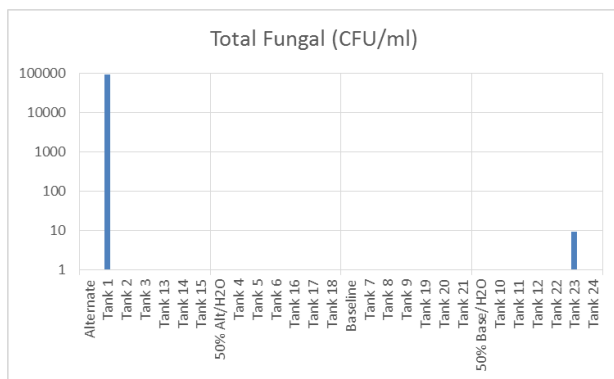


Fig. 18. Only two tanks ended the year with a detectable fungal count, Tanks 1 and 23. Surprisingly, neither of these tanks exhibited visible fungal growth during the test, while several others did, as discussed above. The conclusion is that these two tanks held fungal growths within the fluid, while the others had growths on the surface that did not contaminate the fluids themselves.

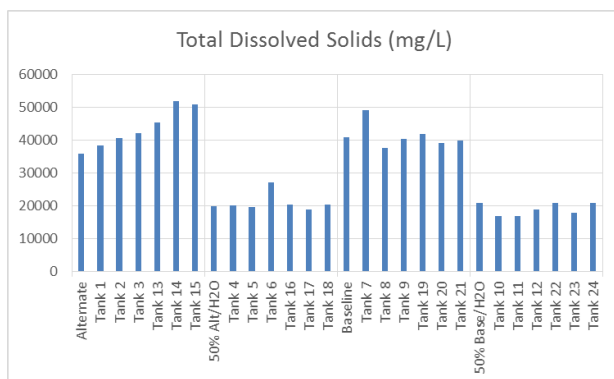


Fig. 19. The undiluted solutions start and end with TDS levels roughly double their 50% diluted counterparts, as would be expected. The diluted solutions appear to have smaller variations than the others. There are no trends indicating a difference between ambient and vacuum pressure tanks.

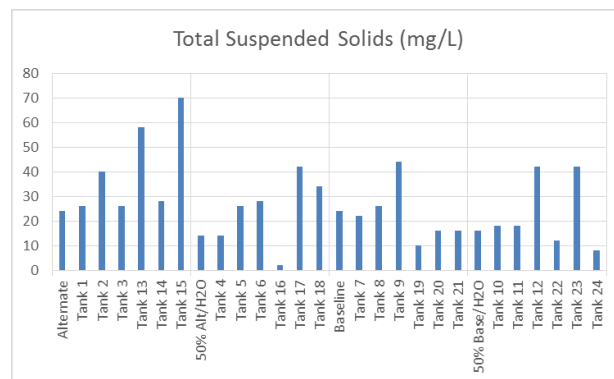


Fig. 20. The starting values for TSS are nearly double for the undiluted solutions as they are for the diluted. This matches the results of the TDS data above. The end results are highly variable. Other than a propensity for the full-concentration alternate solution to produce higher-value results in the absolute sense (a propensity it shares with the TDS), no particular patterns emerge.

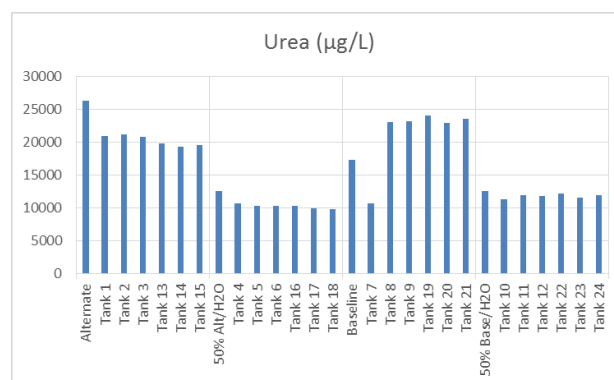


Fig. 21. Urea concentration drops ~20% after a year with the alternate pretreatment solutions, increases with the undiluted baseline pretreatment, and remains steady with the dilute baseline solution. Pressure has little if any effect on this result.

E. Summary of Results

Table 5. Summary of Results

| Results Summary | Alternate: Ambient (1, 2, 3) | 50% Alternate/ H ₂ O: Ambient (4, 5, 6) | Baseline: Ambient (7, 8, 9) | 50% Baseline/ H ₂ O: Ambient 10, 11, 12) | Alternate: Vacuum (13, 14, 15) | 50% Alternate/ H ₂ O: Vacuum (16, 17, 18) | Baseline: Vacuum (19, 20, 21) | 50% Baseline/ H ₂ O: Vacuum (22, 23, 24) |
|---|---------------------------------|--|----------------------------------|--|--------------------------------------|--|-------------------------------------|--|
| Prevents surface fungal growth | No (film) | Yes | Yes | No | No (film) | No (film) | Yes | Yes |
| Prevents suspended fungal growth | No | Yes | Yes | Yes | Yes | Yes | Yes | No |
| Effective bacterial biocide | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Effect on pH | Raise (minimal) | Raise (minimal) | Raise (minimal) | Raise (minimal) | Raise (minimal) | Raise (minimal) | Raise (minimal) | Raise (minimal) |
| Effect on Conductivity | Lower | Lower | Raise | Raise | Lower | Lower | Raise | Raise |
| Effect on Oxidation/ Reduction Potential | Lower | Lower | Lower | Lower | Lower | Lower | Lower | Lower |
| Effect on Specific Gravity | Raise | Constant | Lower | Constant | Raise | Constant | Lower | Constant |
| Effect on Dissolved Solids | Raise | Constant | Inconclusive | Lower | Raise | Constant | Inconclusive | Inconclusive |
| Effect on Suspended Solids | Raise | Raise | Inconclusive | Raise | Raise | Inconclusive | Lower | Inconclusive |
| Effect on Urea | Lower | Lower | Inconclusive (probable raise) | Lower | Lower | Lower | Raise | Lower |
| Effect on Total Inorganic Carbon | Raise | Lower (2/3) | Raise | Raise (2/3) | Lower | Lower | Lower | Lower |
| Goal State: | | | | | | | | |
| Low pH | x | x | x | x | x | x | x | x |
| No bacterial growth | x | x | x | x | x | x | x | x |
| No fungal growth | | x | x | | | | x | x |
| No increase in dissolved solids | | x | | x | | x | | |
| No increase in suspended solids | | | | | | | x | |

Based on the results of this test, the best pretreatment solution for use in a year-long dormancy situation is one of the following:

- 1) Alternate, diluted 50% with water and kept at ambient pressure (Tanks 4-6)
- 2) Baseline, undiluted, kept at 25 psig vacuum (Tanks 19-21)

If the dissolved solids in the baseline solution (tanks 19-21) could be more conclusively determined to either remain constant or decrease, then that option becomes the clear best choice, based on these criteria.

Any of the other options except for the undiluted alternate pretreat (tanks 1-3 and 13-15) would be roughly equivalent, depending on the priorities of the situation. The ambiguous results of dissolved solids formation among ambient baseline (tanks 7-9) and diluted baseline under vacuum (tanks 22-24) give them the edge over dilute ambient baseline (10-12) and dilute alternate under vacuum (16-18).

V. Conclusion

The ISS water system architecture has been reviewed to identify issues related to a one-year dormant period. This assessment was performed by dividing the water system into various regions each with unique conditions and issues related to dormancy. The primacy concern in each region is related to microbial growth in stagnant water systems. Possible solutions were identified for each region, typically including periodic system operation or introduction of a biocide for microbial control.

The second phase of this effort included a test program to evaluate specific susceptibility of pretreated urine to long-term storage. This phase evaluated the chemical and microbial stability of various pretreated urine solutions to support the final assessment. This test effort did not identify a conclusive advantage for the baseline versus alternate pretreated urine, ambient versus vacuum pressure, or dilute versus non-dilute pretreated urine. Given the advantages associated with water recovery from alternate pretreated urine¹, the recommended approach is to use a dilute solution at ambient pressure.

The third phase of the effort is to define architectural and operational concepts that will a) prepare the water systems for the dormant period, b) enable the water systems to be maintained during the dormant period, and c) support the transition of the water system from dormancy to operational when the crew returns to the habitat. This task will address the specific issues identified in the initial assessment, culminating with specific recommendations for sustaining a water management system during and after the extended dormant period.

References

1. Carter, D.L. J. Pruitt, C. Brown, R. Schaezler, and L. Bankers, "Status of ISS Water Management and Recovery", Paper # 073, presented at the 45th International Conference on Environmental Systems, Bellevue, WA, July, 2015